Fuel Cell Tri-Generation System Case Study using the H2A Stationary Model

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Introduction

Goal:

Develop a cost analysis tool that will be flexible and comprehensive enough to realistically analyze a wide variety of potential combined heat and power/hydrogen production scenarios

Approach:

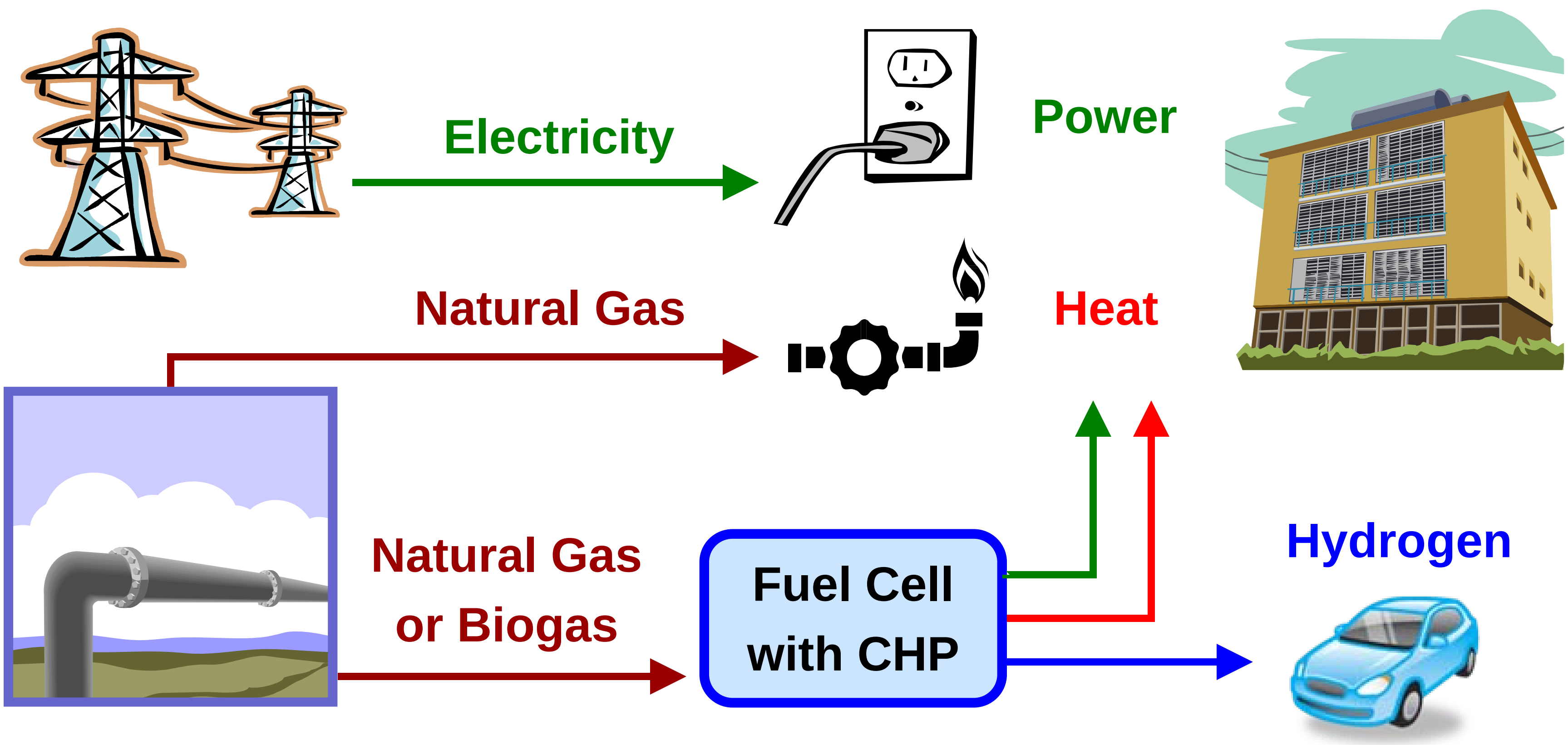
Rely on the H2A discounted cash flow methodology to develop a new stationary systems model

With the help of industry partners, develop and analyze a range of realistic case studies for tri-generation systems.

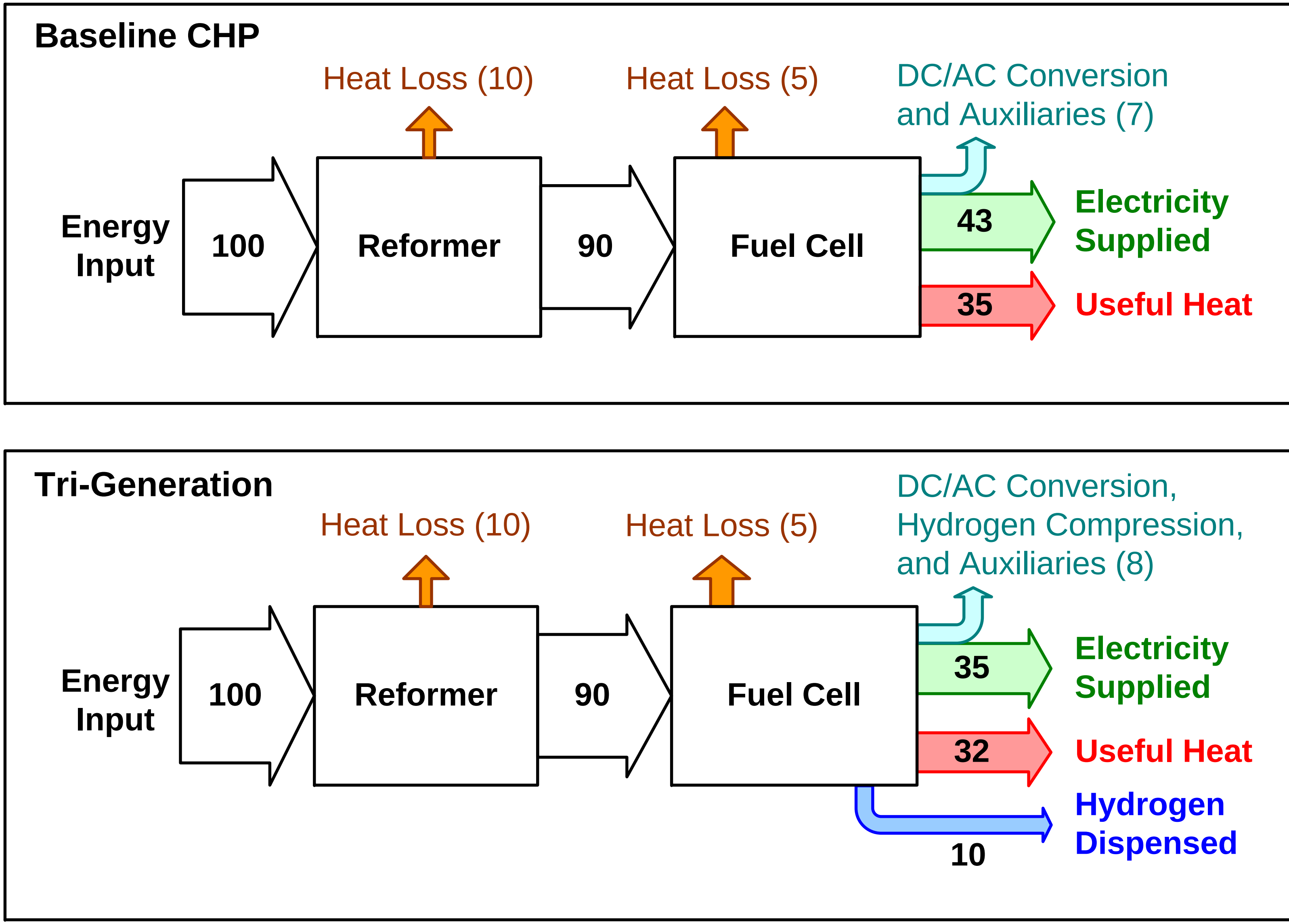
Combined Heat & Power / Hydrogen Production Cost Model Allows Analysis of New Transition Strategies

Hydrogen infrastructure costs for early transition phase are large, and are relatively high risk due to uncertainty of demand

Combining hydrogen production with CHP capability may reduce upfront costs and reduce investment risks



Tri-Generation System Provides Hydrogen as an Additional Output



Combined Heat & Power / Hydrogen Production Concept

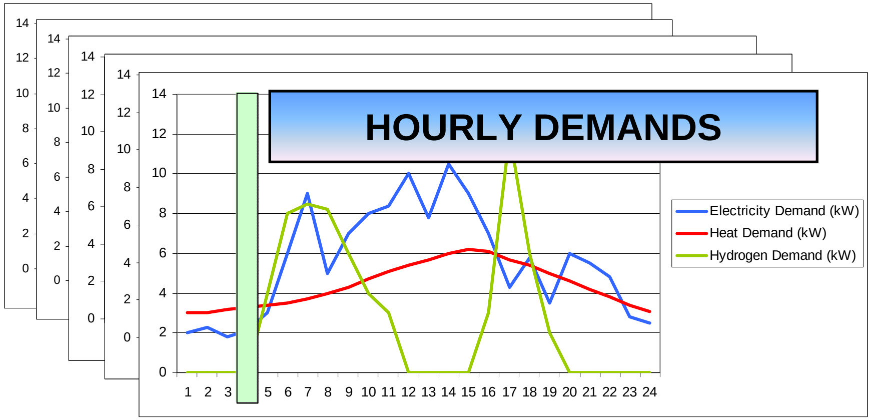
System provides both electricity and heat; replaces electricity from the grid and heat from a furnace or boiler

- More efficient; Heat from the facility is used for space and water heating rather than being wasted.
- Small scale: Heat and electricity are only provided for one or several nearby buildings
- Other advantages such as providing backup power when the grid is not available

Early transition strategy combines above system with hydrogen production capability

- Hydrogen can be produced and stored when electricity and heat demand are low
- Stored hydrogen can be used later to produce more electricity or as vehicle fuel

H2A Stationary Model Concept

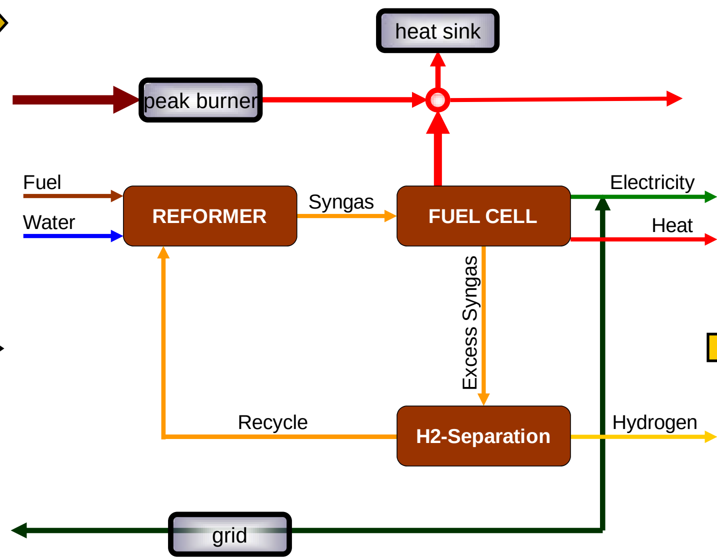


LEVELIZED COST OF ENERGY SUPPLIED BY THE SYSTEM

H2A NET PRESENT VALUE/CASH FLOW ANALYSIS

- Financial inputs
- Capital cost input
- Replacement costs
- Operating costs

GRID ELECTRICITY AND FUEL PRICE SCHEDULES



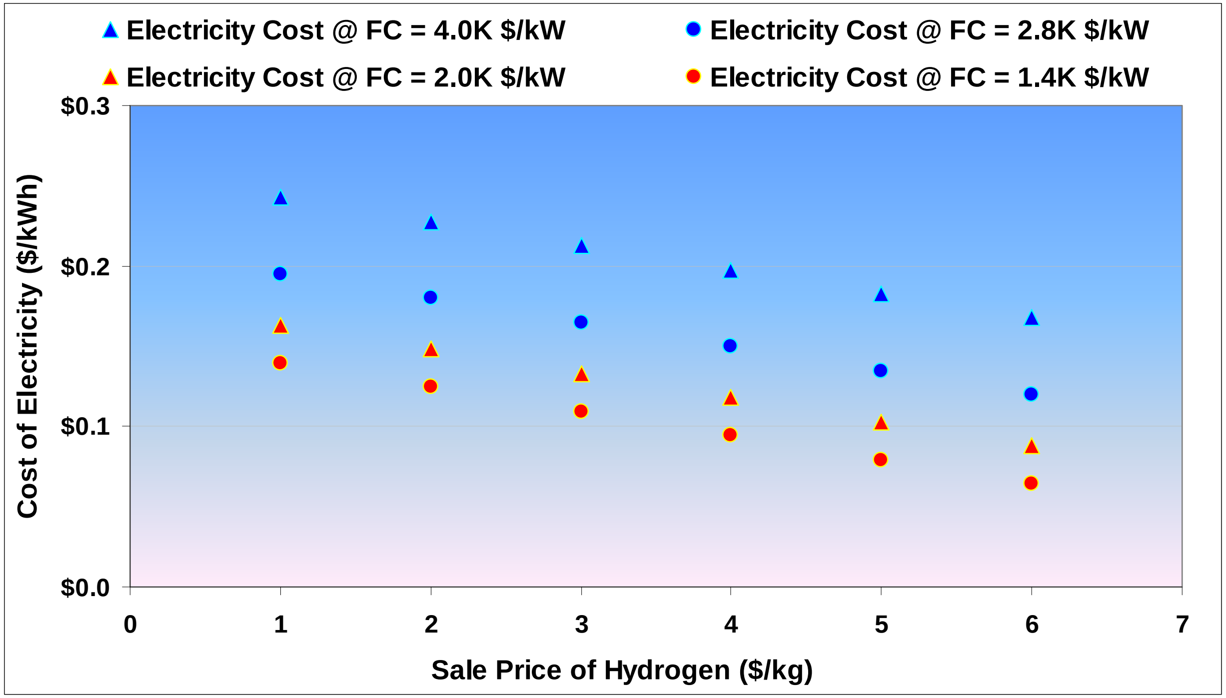
HOURLY ENERGY FLOWS AND $

- Delivered electricity
- Delivered heat
- Delivered hydrogen
- Fuel used
- Used grid electricity
- Sales to grid

Model Results - Cost Allocation

Primary Result is:

- Total Cost of Delivered Energy ($/kWh)
  - Electricity Produced and Used Onsite or Sold
  - Heat Produced and Used Onsite
  - Hydrogen Produced



The model also calculates the total energy efficiency and emissions

H2A Stationary model tool facilitates analysis of energy use and production and lifetime costs for CHP/ hydrogen production systems.

Energy Analysis module analyzes hourly energy inputs and outputs

- Analysis uses hourly demand profiles (heat and electricity) that can be downloaded for specific building types in specific locations or entered by the user
- Analysis uses hourly profiles for renewable resources that can be downloaded for specific locations
- Flexible configuration of:
  - Reformer operating on a wide variety of fuels
  - **High temperature fuel cell/reforming fuel cell**
  - Electricity from renewable sources (wind and solar)
  - Electrolyzer
  - Low temperature hydrogen fuel cell
  - Supplemental heat supply and connection to the grid for supplemental electricity
- Dynamic model of reformer and fuel cell efficiency as a function of turndown gives more realistic analysis of the effect of load following
- Can be set to follow either heat or electricity demand profile

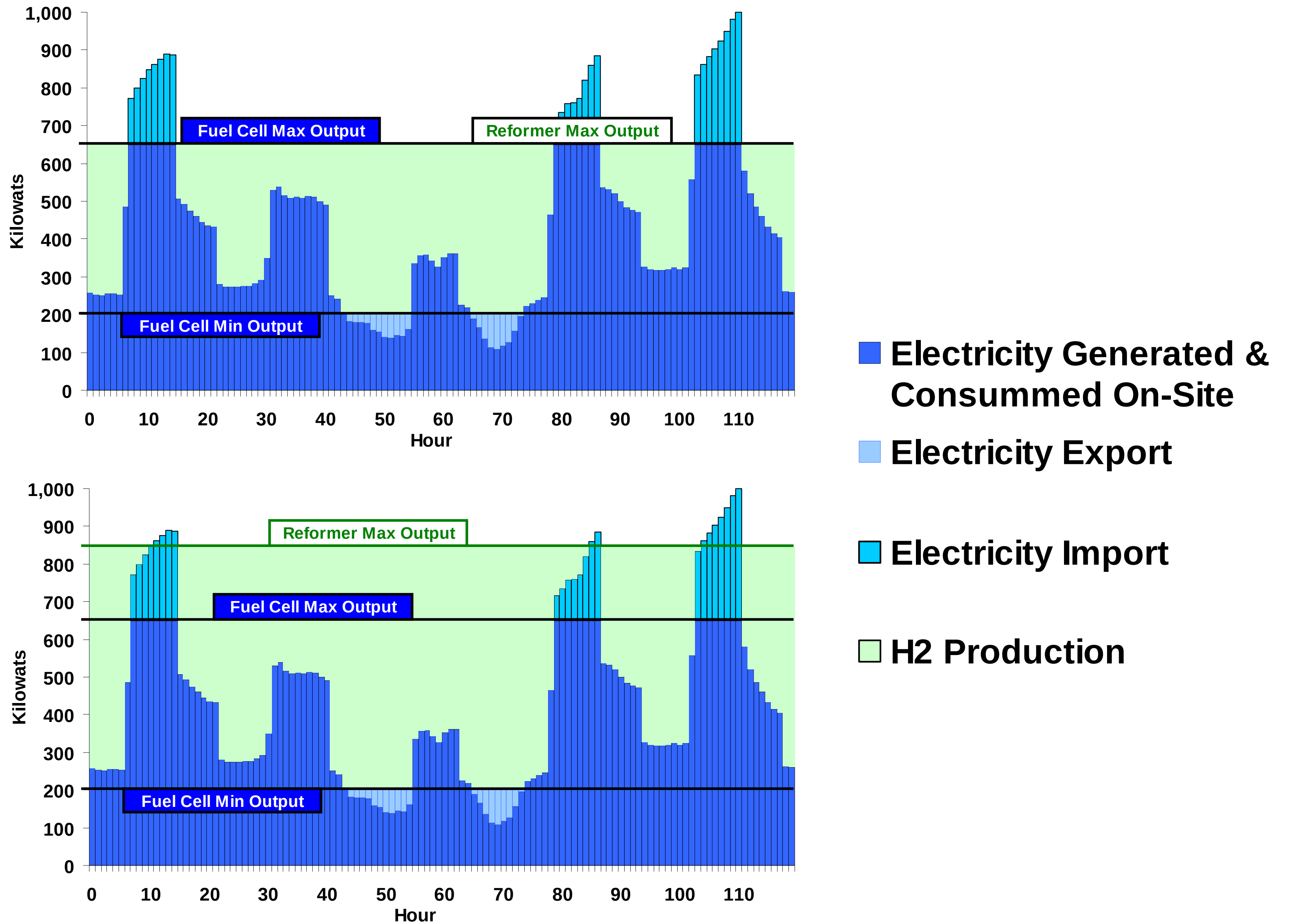
Flexible Fuel Cell System Configuration Accommodates Different Types of Fuel Cells and Reformers

User can specify a separate reformer and fuel cell or an integrated reforming fuel cell system

User Defined Values

- Maximum and minimum fuel cell AC power output
- Fuel cell electrochemical efficiency as a function of operating fraction
- Inverting efficiency
- Heat recovery efficiency
- Maximum reforming capacity (reformer can be matched to provide the fuel cell at rated power including losses or the reformer can be “oversized” to produce additional hydrogen)
- Maximum ramp rate (% of rated power per hour)
- Hydrogen purification efficiency
- Auxiliary power requirements
- Water use

Size of Reformer and Fuel Cell Can be Adjusted Separately



Potential Applications

Facility	Application	CHP/tri-generation System
Airport	•AC power for terminals and other buildings •Space and water heating •Backup power for critical systems •Luggage tugs/trains/carts •Airport taxi and bus services	CHP System CHP System CHP/Hydrogen FC Hydrogen vehicles Hydrogen vehicles
Military Base	•AC power for buildings •Space and water heating •Backup power for critical systems •Forklifts/warehouse operations •Onsite vehicles (security, buses, etc.)	CHP System CHP System CHP/Hydrogen FC Hydrogen vehicles Hydrogen vehicles
Hospital	•AC power for buildings •Space and water heating •Backup power for critical systems •Public hydrogen dispensing	CHP System CHP System CHP/Hydrogen FC Hydrogen vehicles
Post Office	•AC power for buildings •Space and water heating •Public hydrogen dispensing •Fleet refueling	CHP System CHP System Hydrogen vehicles Hydrogen vehicles

Strategy for Analysis of Chicago Hospital

1. Develop a CHP-only system to determine the cost of generating electricity and heat

PAFC System

Stack Operating Temperature = ~200°C

Supplemental burner - Assumed to be natural gas furnace at 95% efficiency. (existing building heating system)

No natural gas supply infrastructure upgrades required.

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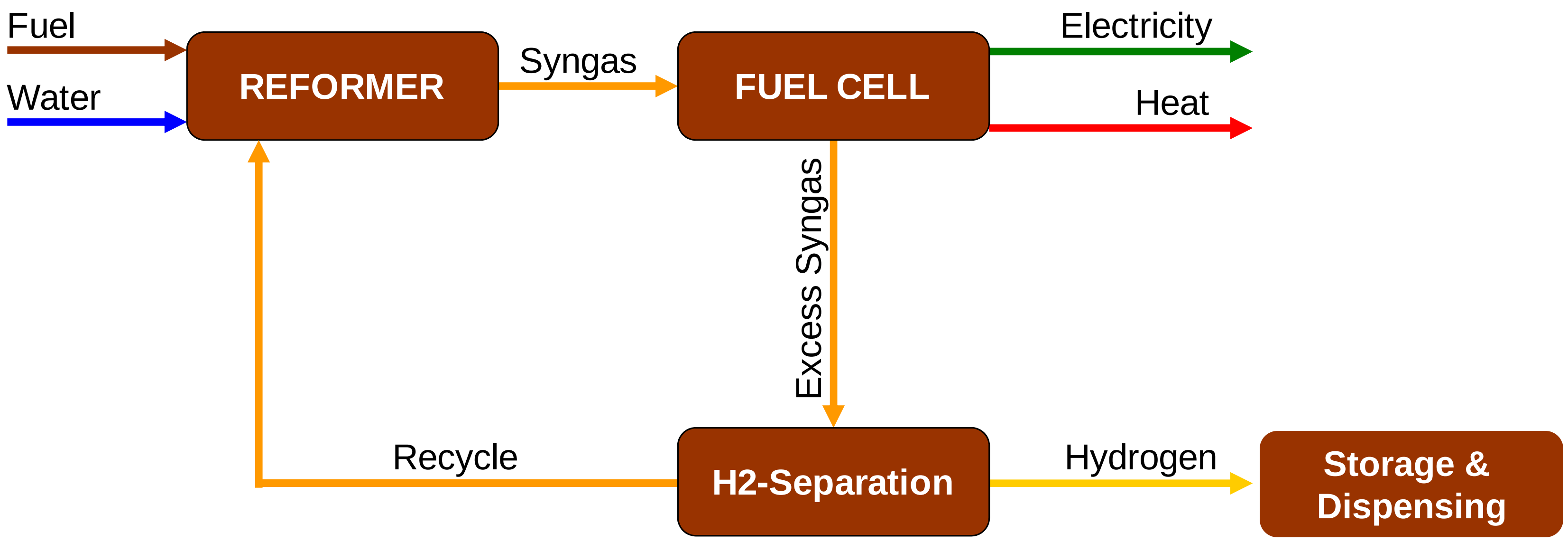
Simple CHP / Hydrogen System for a Chicago Hospital



Hydrogen storage = 1.17 x daily demand (350 kg/day)

All storage at 6250 psi

1 compressor, 1 dispenser

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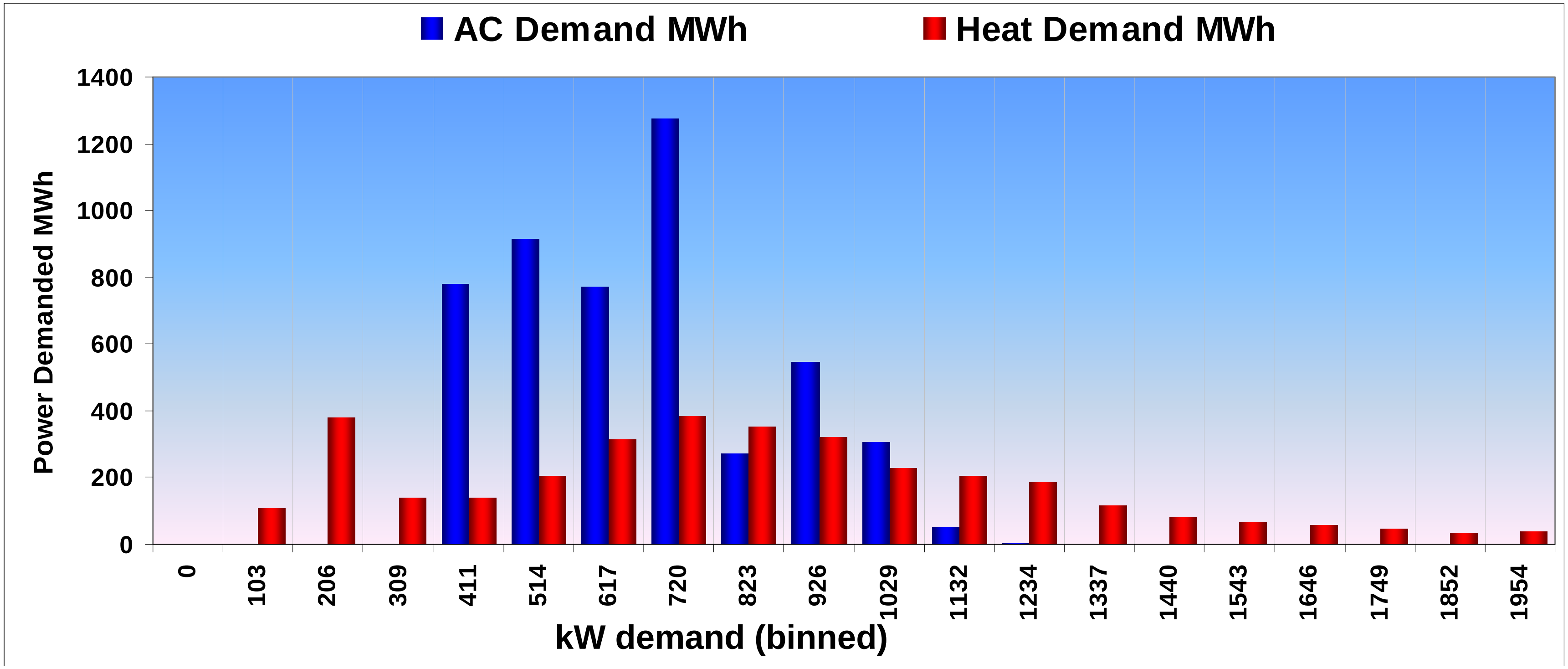
Demand Profile of Chicago Hospital



Building Demand Profiles	
Electricity	**Heat**
Maximum = 1160 kW	Maximum = 1950 kW
Average = 554 kW	Average = 390 kW
Total annual = 4,850 MWh	Total annual = 3,440 MWh

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System Cost Parameters

	CHP Only System	Tri-Generation System
Fuel Cell AC Rating	830 kW	
Fuel Cell Installed Cost	$3,030/kW AC	
Fuel Cell Total Cap	**$2,520,000**	
Reformer Installed Cost	$970/kW AC (reformer/fuel cell system AC output)	
Reformer Oversize Factor	1	
Reformer Total Installed Cost	**$805,000**	
H2 Purification Installed Cost	**N/A**	**$60,400**
H2 CSD Total Installed Cost	**N/A**	**$622,000**
Total System Installed Capital Cost	**$3,325,000**	**$4,007,000**

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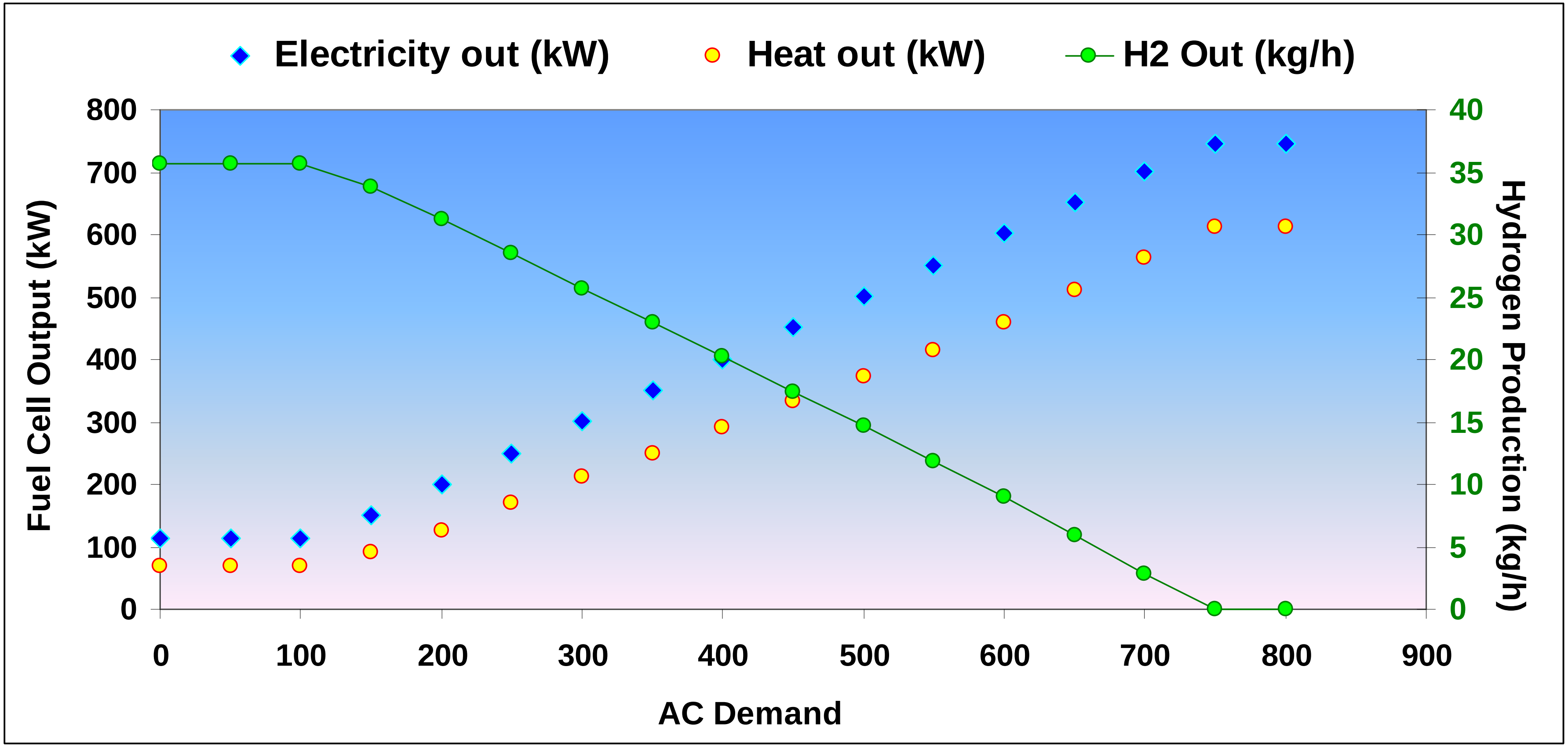
Tri-Generation System Energy Output



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Federal Incentives – Fuel Cells

Business Energy Tax Credit

(H.R. 1424 Div. B The Energy Improvement and Extension Act of 2008)

- Extends the existing tax credit by 8 years
- Applies to Commercial, Industrial, and Utility Sectors
- <u>30% of expenditures or $3,000 per kW whichever is smaller</u>
  - Minimum capacity of 0.5 kW
  - Electricity only efficiency of 30% or greater
- Prior to October 3, 2008 the credit was capped at $1,000/kW

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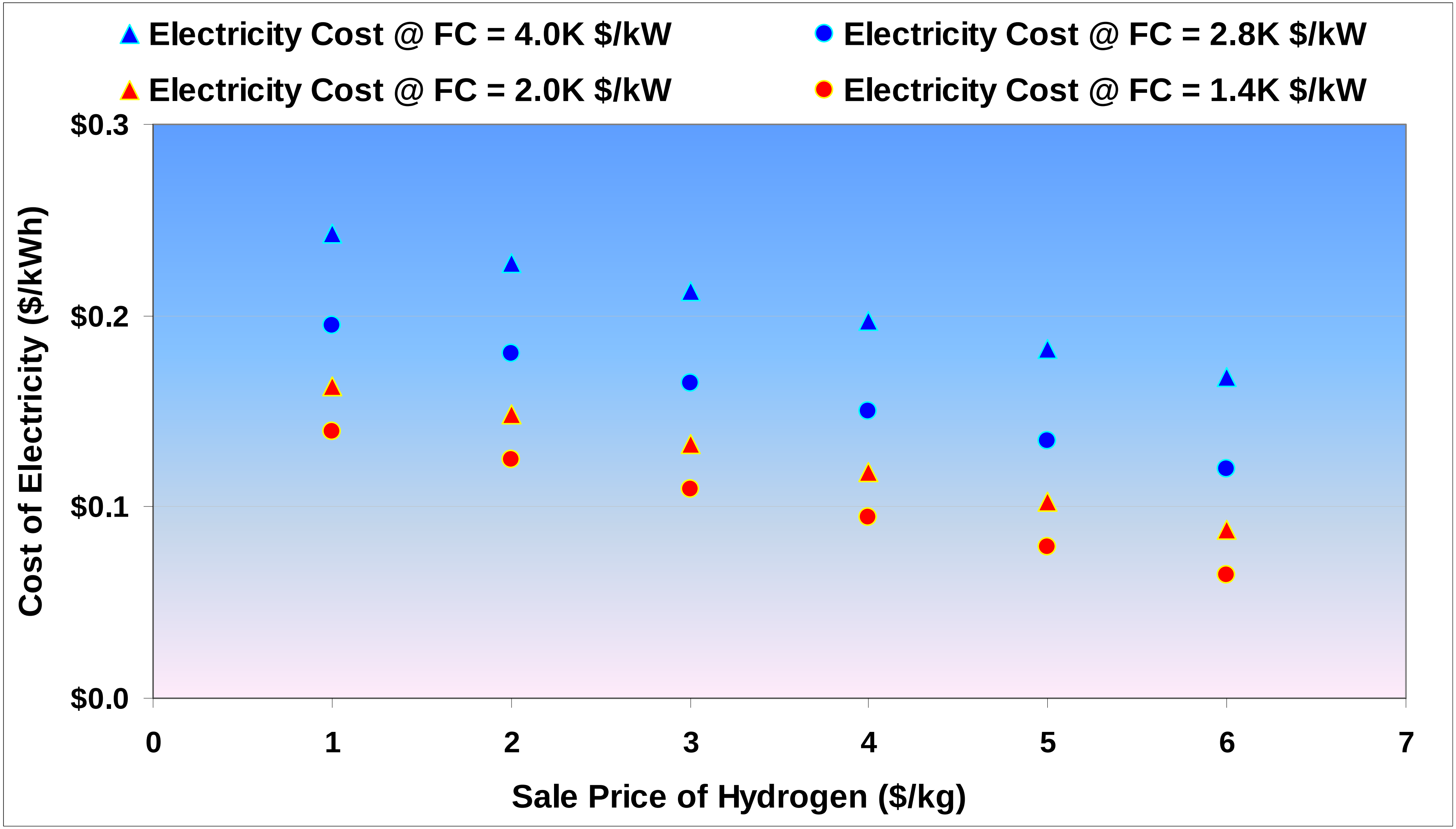
Hydrogen Cost Sensitivity – Electricity Price



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Summary

- The H2A stationary model structure has been developed
- We are working with industry partners to develop cost and performance characteristics for various types of equipment
- The tool will be used to evaluate realistic case studies that examine the impact of:
  - Installation location
  - Building type
  - Grid electricity hourly price structure
  - Equipment configuration and size
  - Operating strategies

Thanks!

Questions?

BACKUP SLIDES

System Performance Parameters

	CHP Only System	Tri-Generation System
Fuel Cell Maximum and Minimum Power	830 kW (max) 166 kW (min) (5:1 turndown ratio)	
Fuel Cell Electrochemical Efficiency (AC LHV basis)	70.2% at min operating fraction (CV = 0.88) 56.7% at 100% of rated power (CV = 0.71)	
Annual Average System Efficiency (LHV basis)	65% AC, heat and hydrogen delivered from reformer/fuel cell system	
Fuel Cell Max Ramp Rate	100% per hour	
Inverting Efficiency	93%	
Minimum FC Reformate Usage	10%	
AC Production Auxiliaries	0.05 kW ac/kW ac	
Heat Production Auxiliaries	0.01 kW ac/kW thermal	
H2 Purification Auxiliaries	N/A	0.033 kW

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Federal Incentives – Fuel Cells

Residential Renewable Energy Tax Credit

(H.R. 1424 Div. B The Energy Improvement and Extension Act of 2008)

- Extends the existing tax credit by 8 years
- Applies to Residential Sector
  - Home must be the principal residence of the taxpayer
- 30% of expenditures up to $500 per 0.5 kW per person claiming the credit
  - Minimum capacity of 0.5 kW
  - Electricity only efficiency of 30% or greater
  - Maximum of $1,667/ 0.5 kW for all claimants combined

Federal Incentives – Fuel Cells

Renewable Energy Production Incentive

Federal incentive payments of 1.5c/kWh (1993$ indexed for inflation) during the first 10 years of operation

- Eligible electric production facilities;
  - Not for profit cooperatives, public utilities, state governments, commonwealths, territories, DC, tribal governments, or a political subdivision thereof and Native Corporations
  - Electricity must be generated from renewable sources (including biomass derived hydrogen for fuel cells)
- Subject to availability of appropriations.

Federal Incentives - CHP

New tax credit for Combined Heat and Power (CHP) systems under HR 1424

- Applies to Commercial, Industrial, and Utility Sectors
- Applies to systems up to 50 MW that exceed 60% energy efficiency
  - Efficiency requirement waived for systems that use biomass for at least 90% of the system energy source (but credit may be reduced)
- Credit equal to 10% of expenditures

Other Federal Incentives

Accelerated depreciation

2005 Energy Policy Act (EPAct 2005) specified a 5 year depreciation schedule for fuel cells

Economic Stimulus Act of 2008:

- 50% bonus depreciation - Owner can deduct 50% of adjusted basis in 2008
  - Fuel must be renewable
  - Fuel cell must be acquired in 2008.
  - Fuel cell must be placed in service in 2008, or in limited cases in 2009
  - 20 year or less depreciation under normal MACRS rules
  - Claimant must be the operator

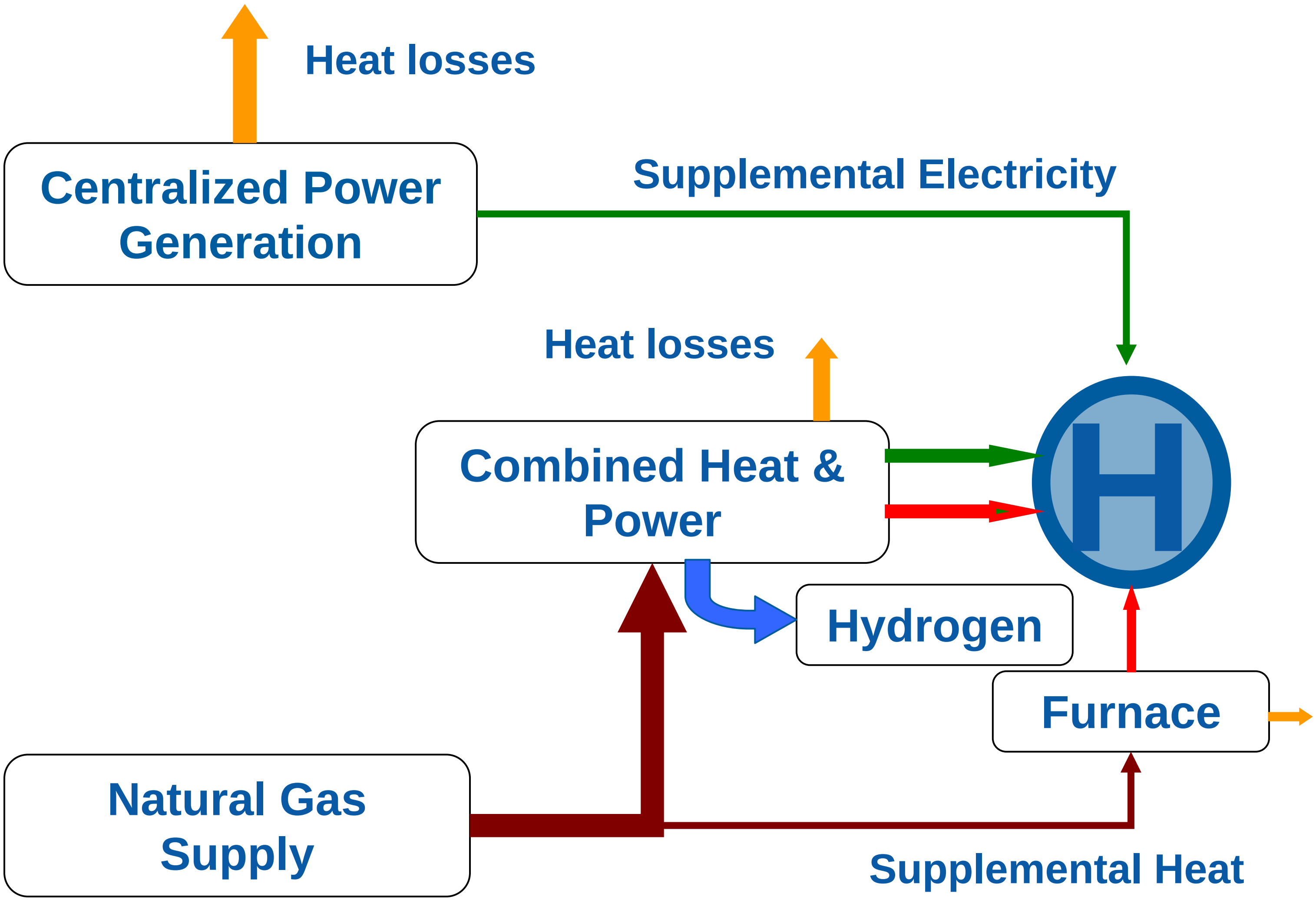
Loan Guarantee Program

State Programs

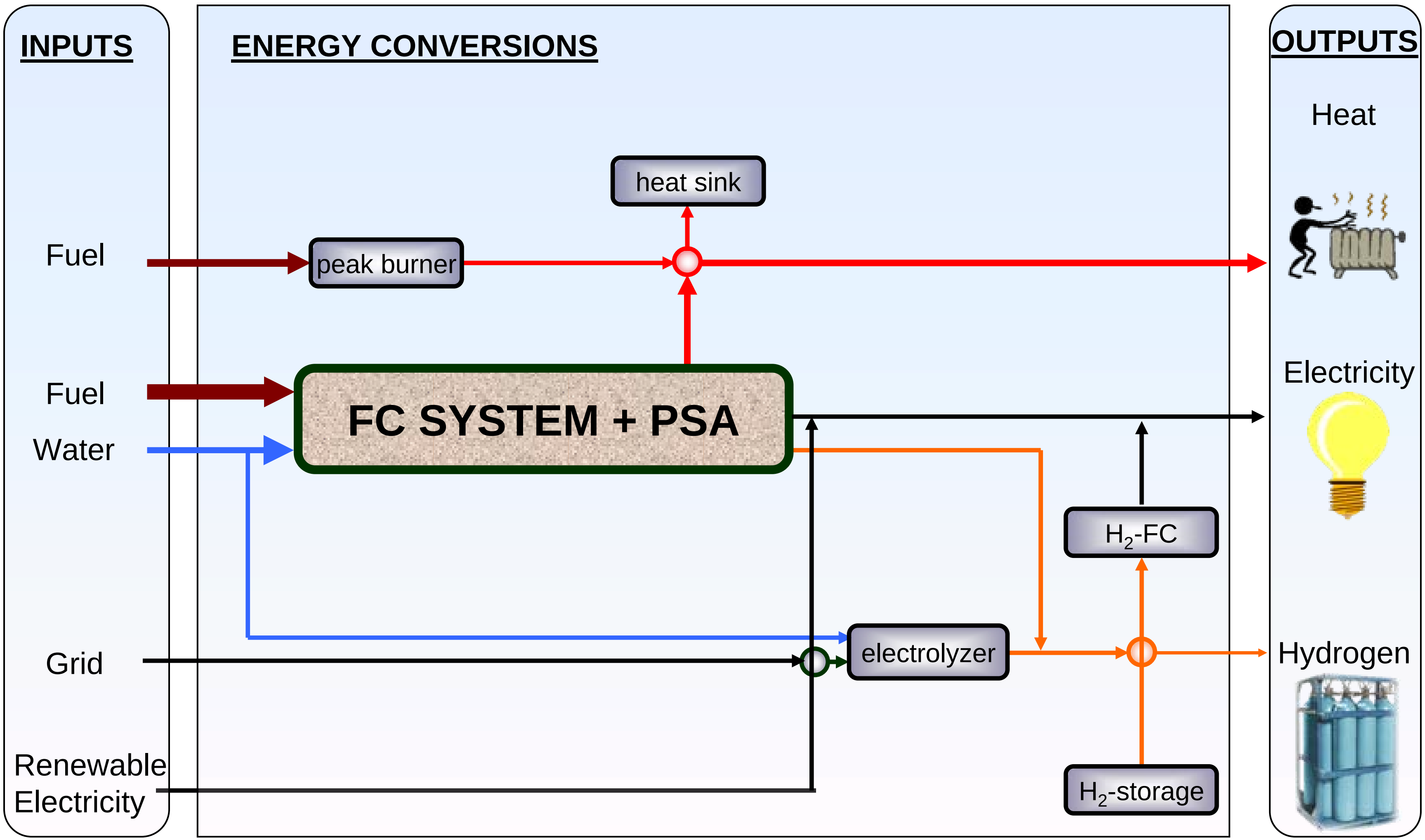
Typically only apply to fuel cells using a renewable energy source

- Grant programs (feasibility studies, design and construction)
- Interconnect standards (distributed generation)
- Renewable Portfolio Standards
- Net metering rules
- Feed-in tariffs (production incentives setting buy/sell prices)
- Rebate programs
- Low interest loans
- Tax exemptions
- R&D grants
- Demonstration projects

Combined Heat & Power / Tri-Generation System Replaces Conventional Energy Supply and Separate Hydrogen Supply



Hourly Energy Analysis – Model Energy Supply According to Prioritization Rules



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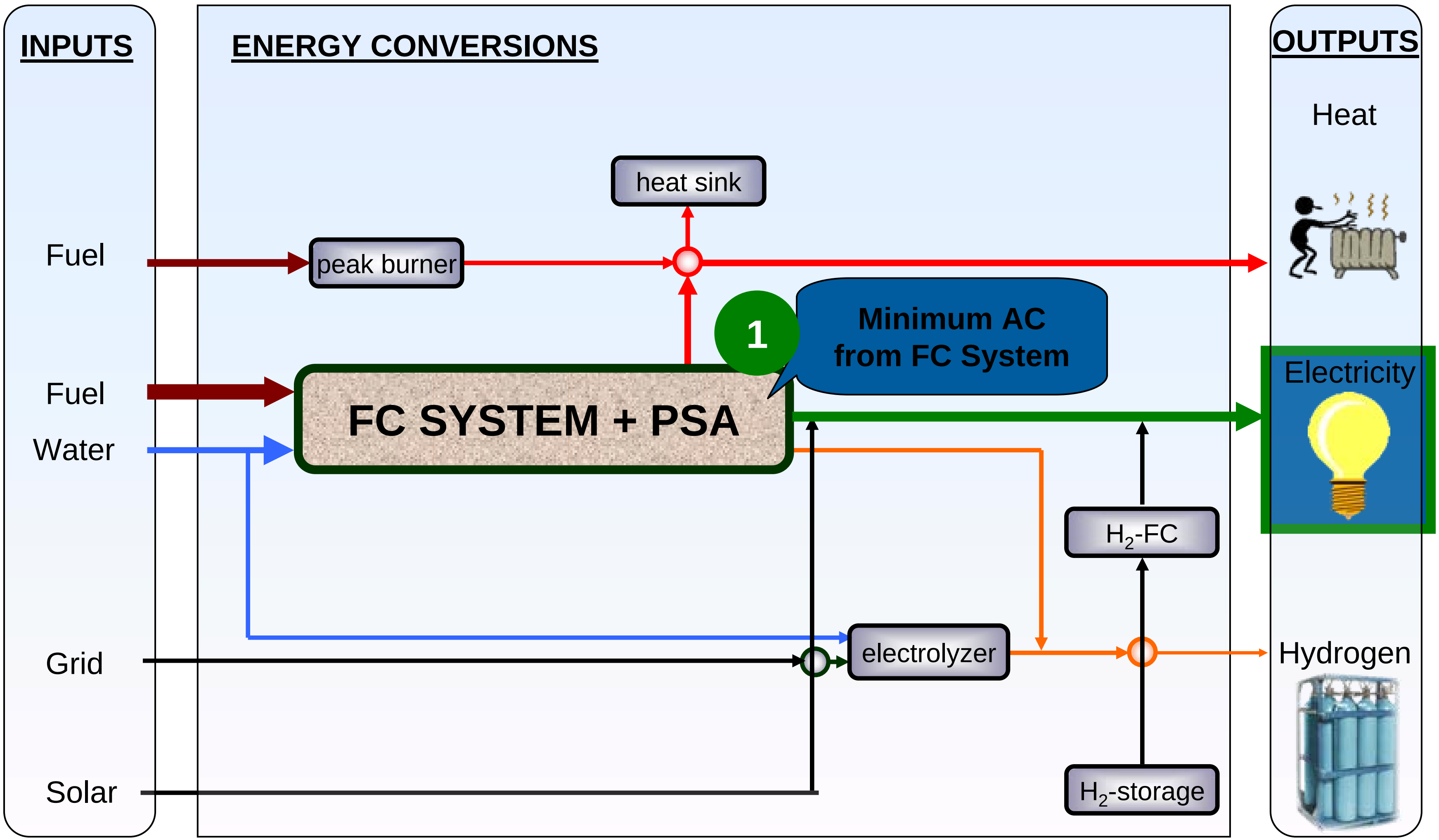

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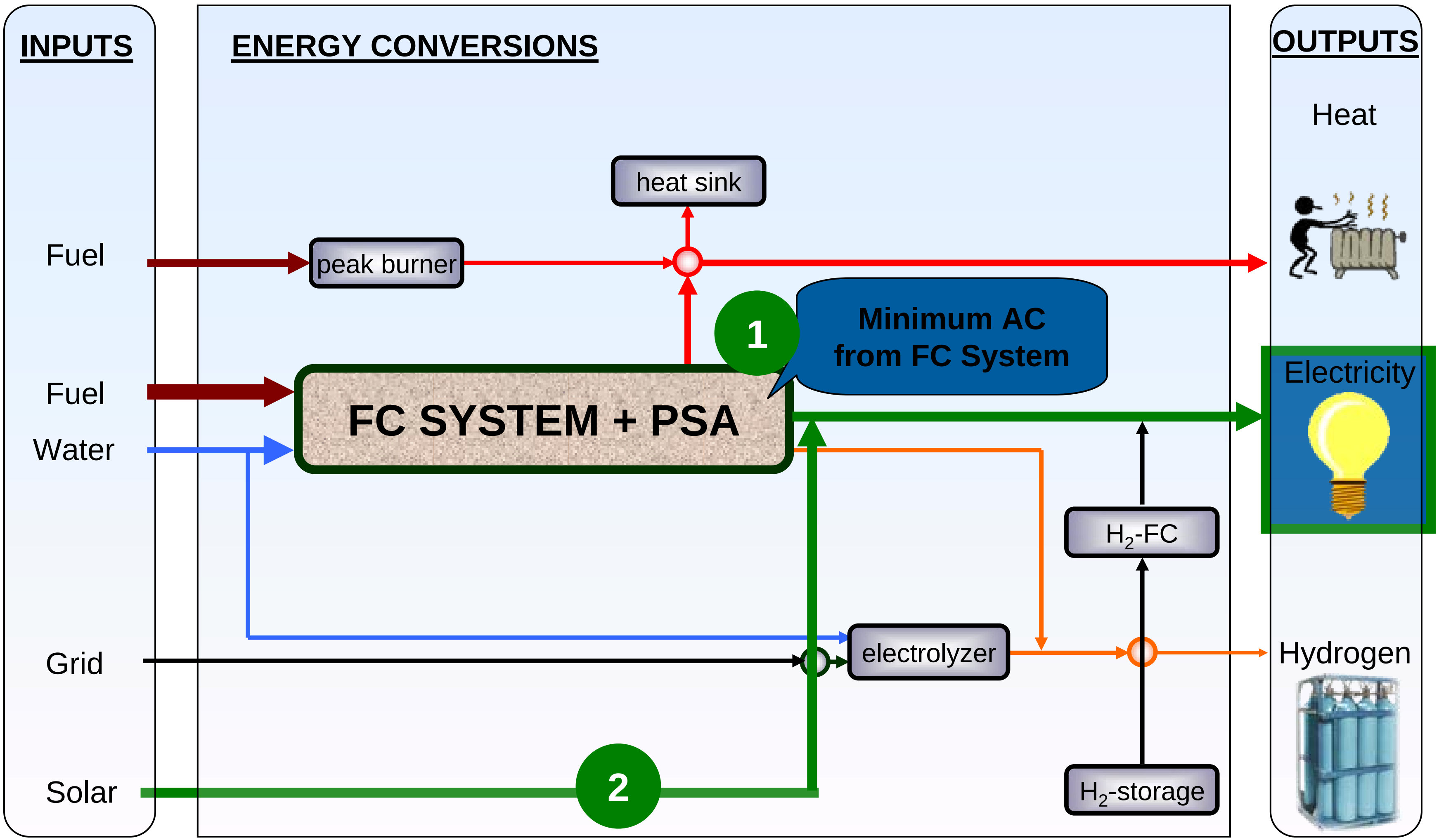

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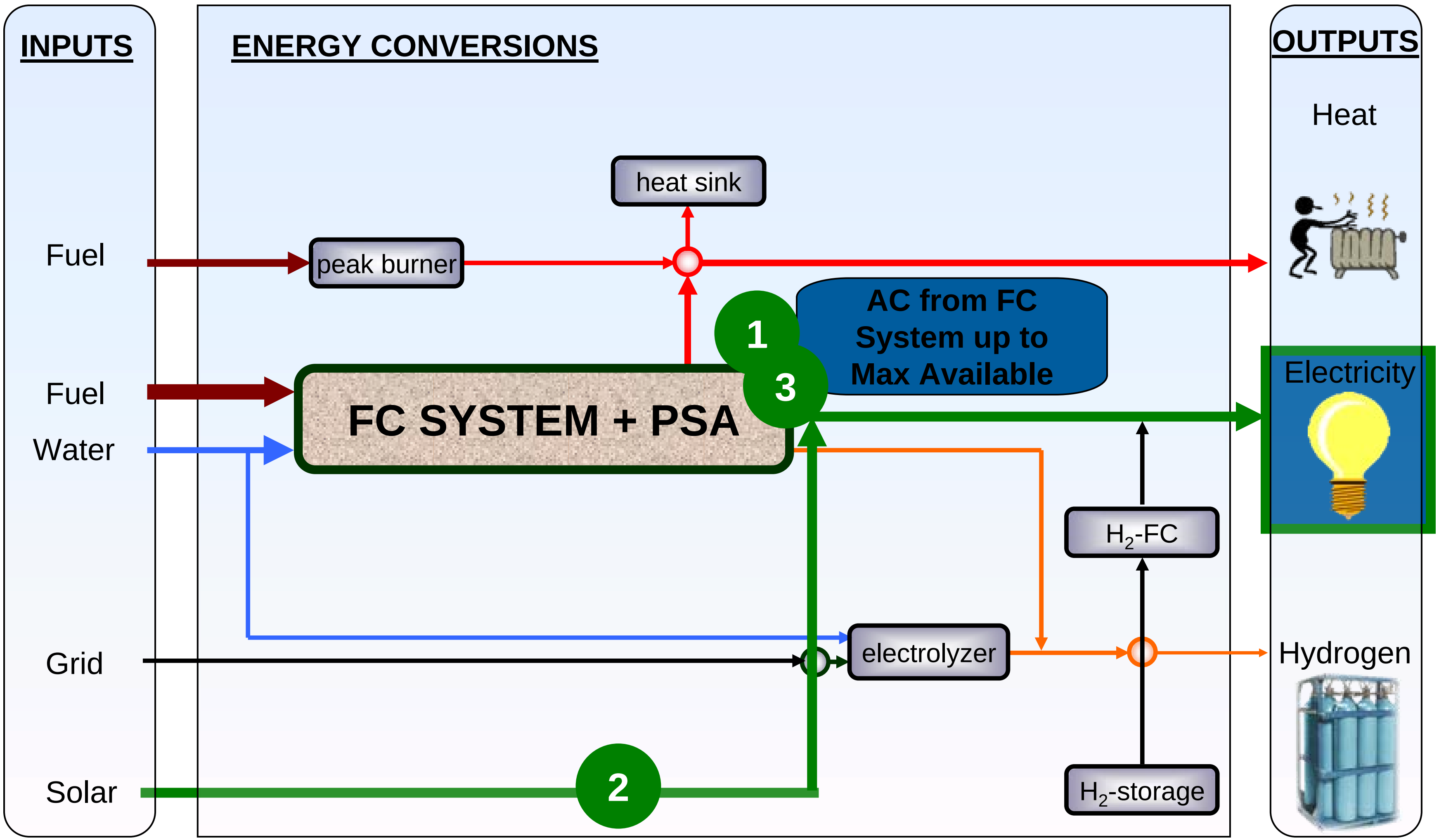

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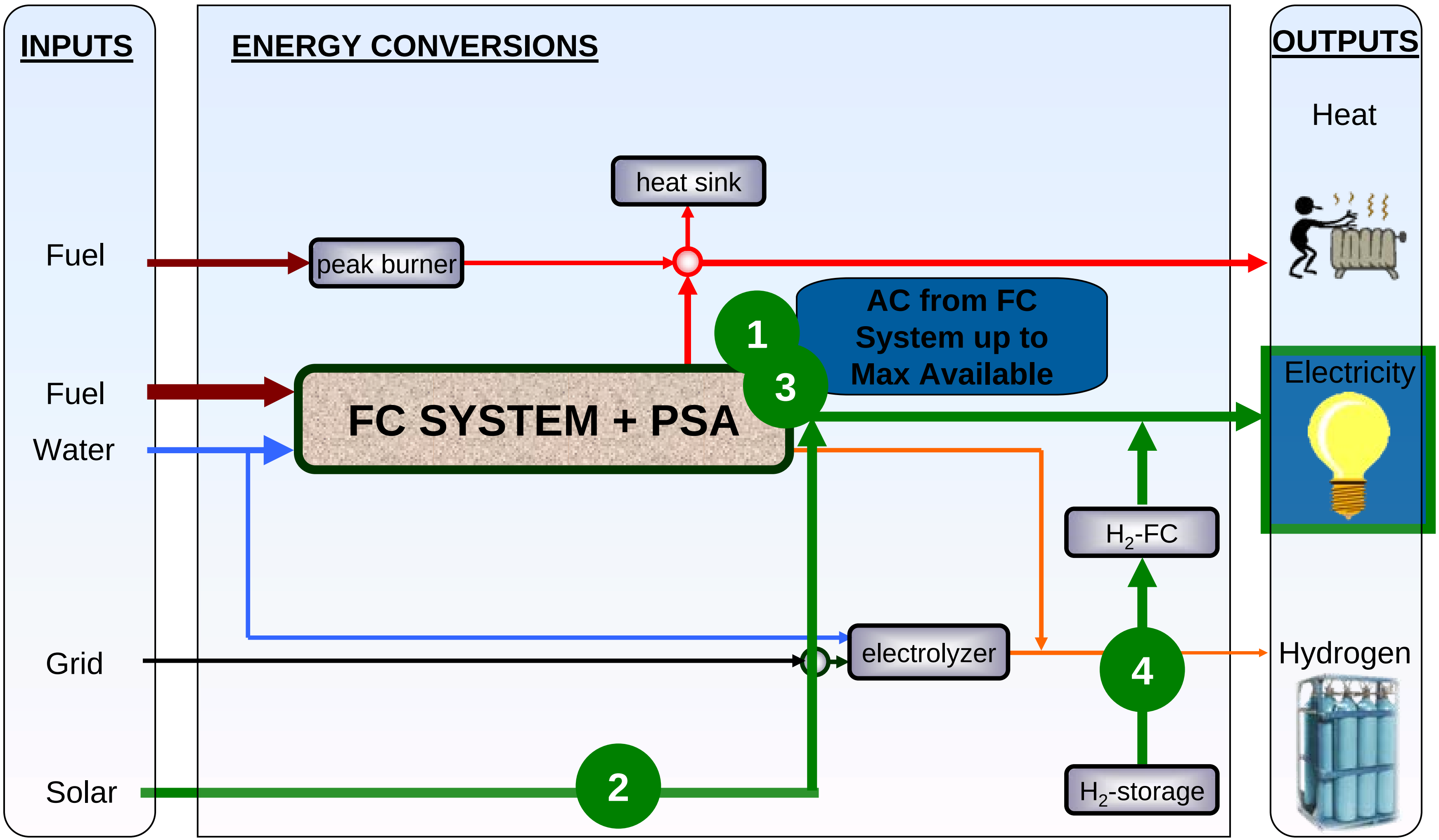

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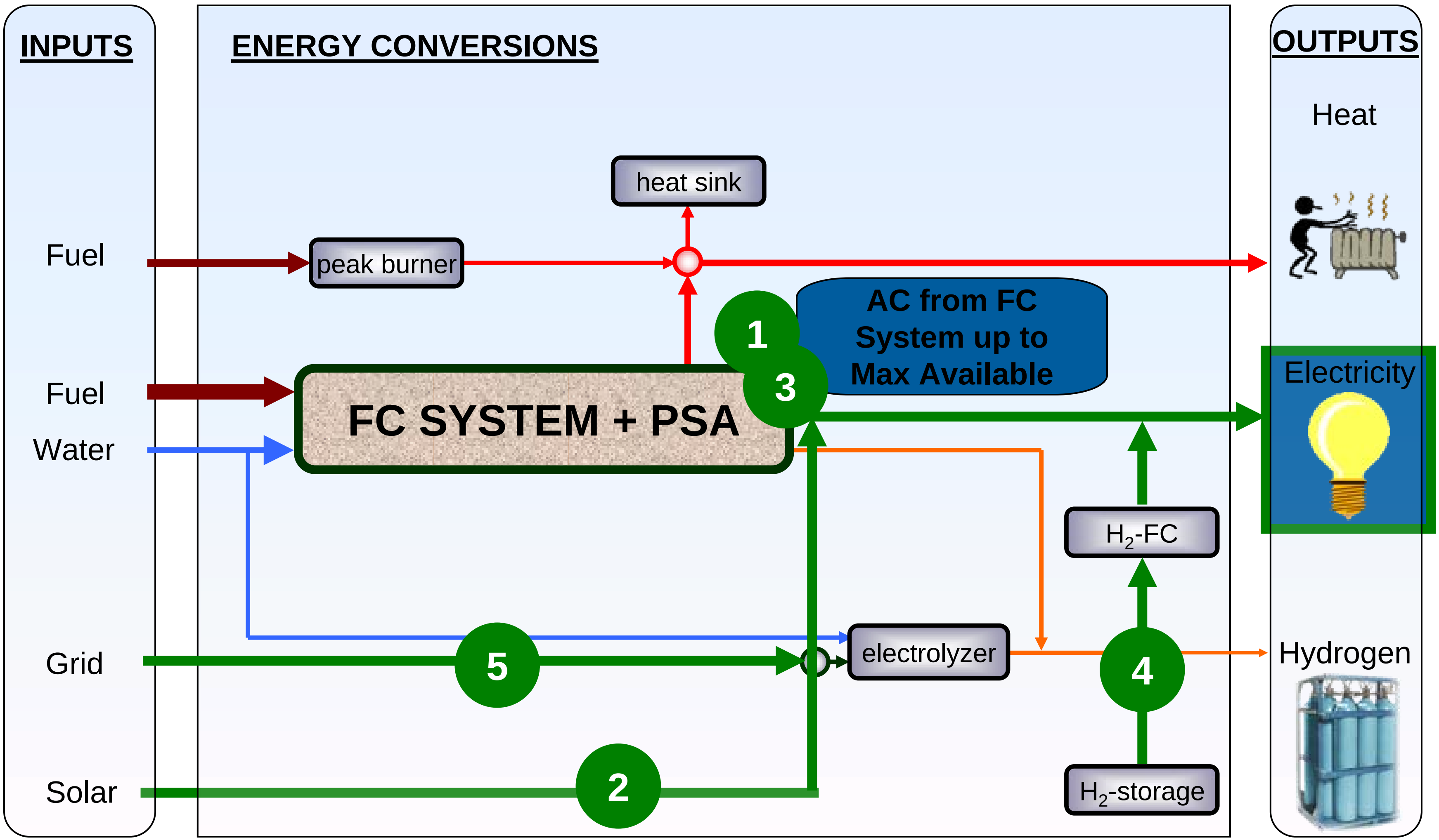
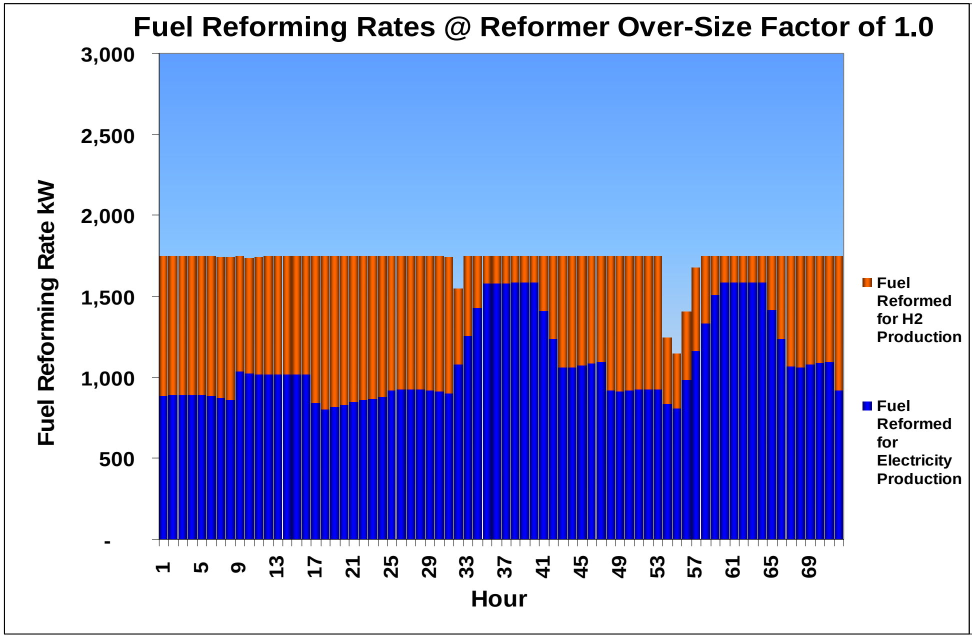
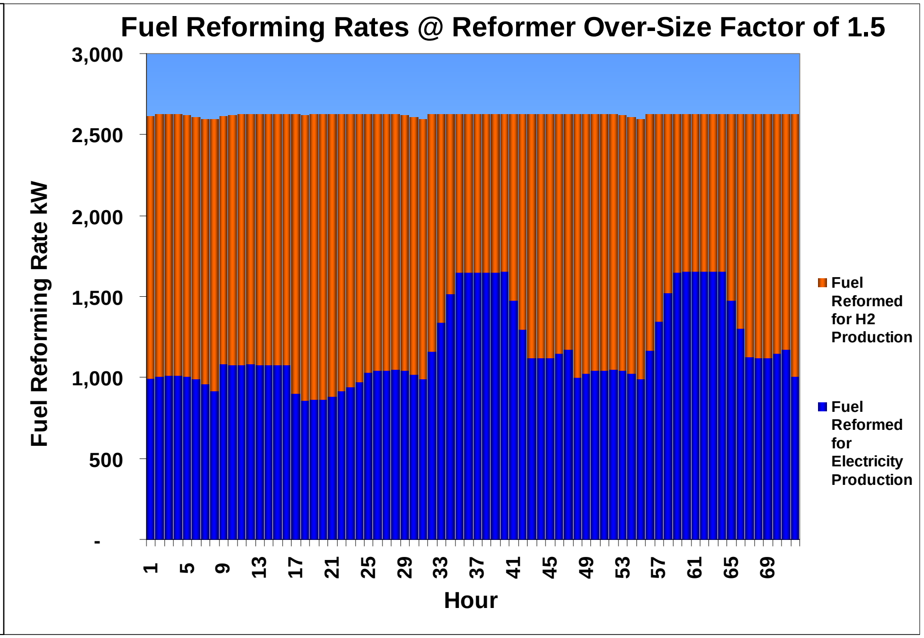


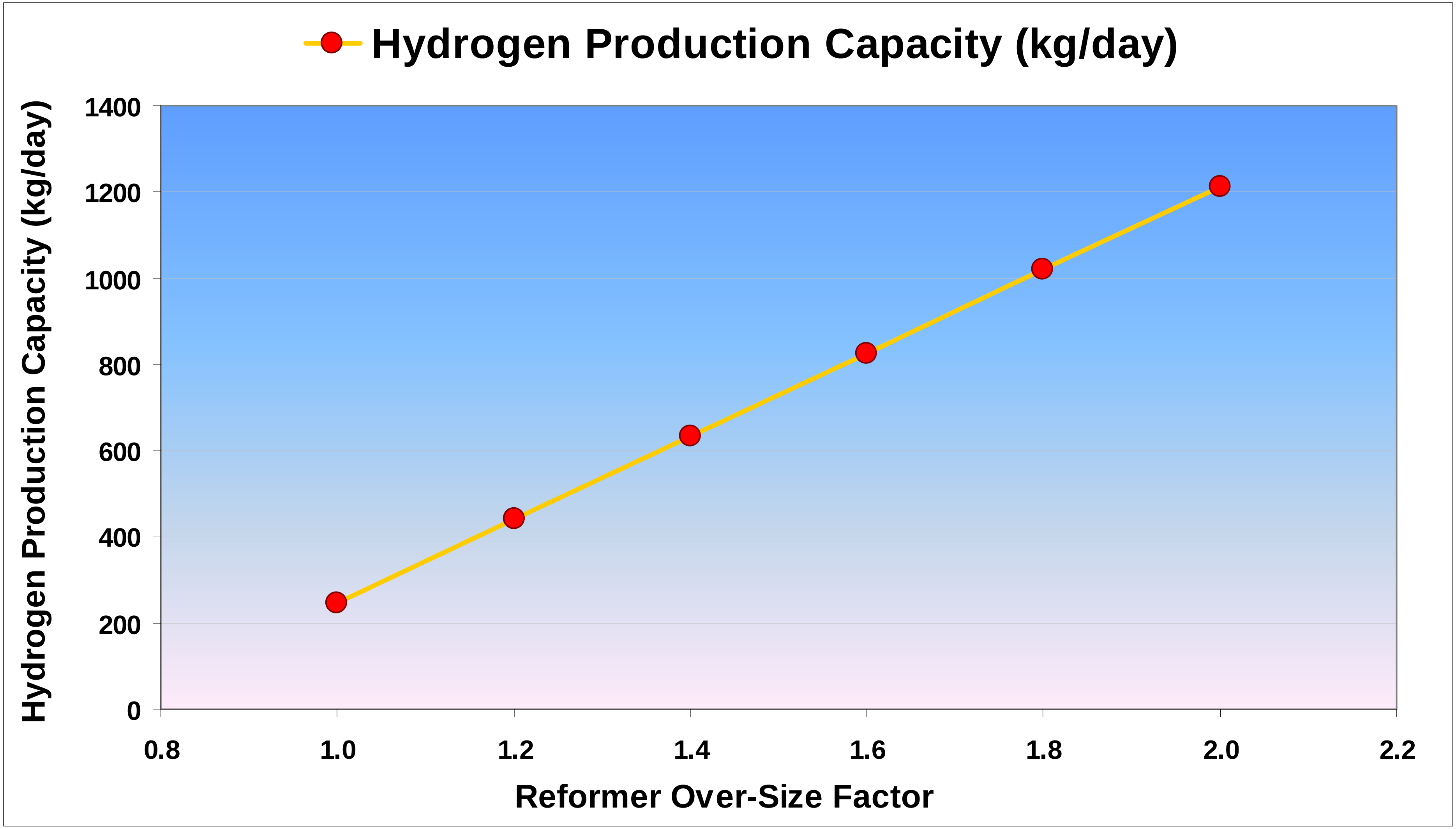
Reformer Over-Sizing Effect





<u>**Oversize Factor:**</u>

- Sensitivity of reformer over-sizing was performed
- 1.0 = Reformer size needed for Max. Fuel Cell output
- Larger reformers allow for more excess reformate to be produced


Hydrogen Production Capacity (kg/day)
Hydrogen Production Capacity (kg/day)
1400
1200
1000
800
600
400
200
0
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Reformer Over-Size Factor

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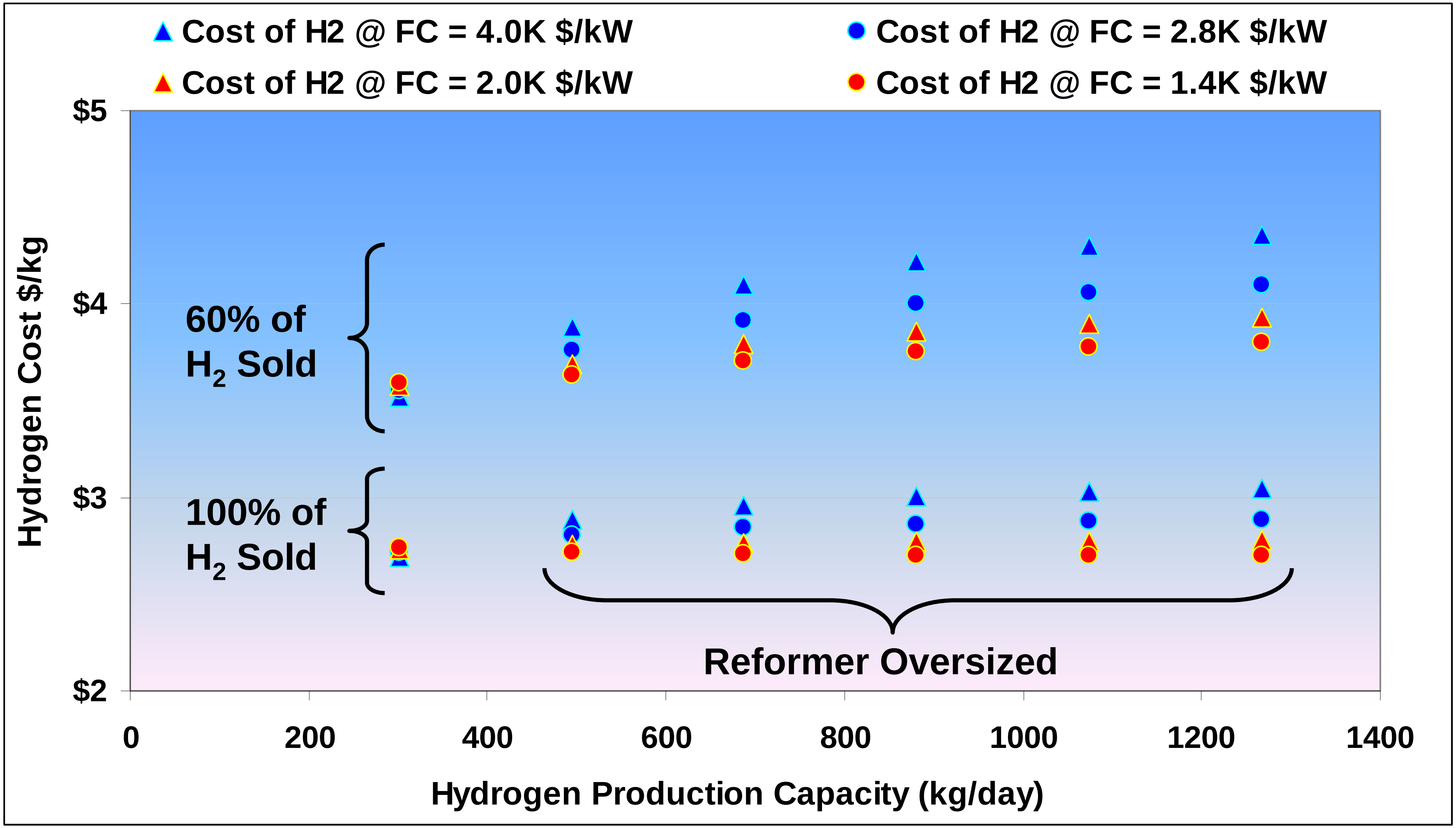
Hydrogen Cost Sensitivity – Reformer Size



Hydrogen cost increases with increased reformer oversize factor

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Combined Heat & Power / Hydrogen Production Cost Model Allows Analysis of New Transition Strategies

Energy Analysis module hourly output is summed over the year and results are used as the energy inputs and outputs for the cost model

Cost Model is based on the H2A hydrogen production discounted cash flow tool

- Consistent with analyses for hydrogen-only facilities so strategies can be compared on an equivalent basis
- Accounts for facility lifetime capital and operating costs